3.3 HAZARD PROFILES

3.3.1 Earthquake

An ***earthquake*** is ground shaking and radiated seismic energy caused most commonly by a sudden slip on a fault, volcanic or magmatic activity, or other sudden stress changes in the earth. An earthquake of magnitude 8 or larger on the Richter Scale is termed a great earthquake. Fortunately, Montana has not experienced a great earthquake in recorded history. A great earthquake is not likely in Montana but a major earthquake (M 7.0-7.9) occurred near Hebgen Lake in 1959 and dozens of active faults have generated M 6.5-7.5 during recent geologic time.

3.3.1.1 Background

- Magnitude and intensity are used to describe seismic activity from earthquakes.
- Magnitude (M) is a measure of the total energy released. Each earthquake has one magnitude, usually measured on the Richter Scale
- Intensity (I) is used to describe the effects of the earthquake at a particular place. Intensity differs throughout the area and is given a value on the Modified Mercalli Scale .
- Seismic events may lead to landslides, uneven ground settling, flooding, and damage to homes, dams, levees, buildings, power and telephone lines, roads, tunnels, and railways. Broken natural gas lines may cause fires.
- Scientists continue to study faults in Montana to determine future earthquake potential. Faults are cracks in the earth's crust along which movement occurs.
- Thousands of faults have been mapped in Montana, but scientists think only about 95 of these have been active in the past 1.6 million years (the Quaternary Period).
- Although it has been over four decades since the last destructive earthquake in Montana, small earthquakes are common in the region, occurring at an average rate of 7-10 earthquakes per day.
- The largest earthquake in Montana, the 1959 Hebgen Lake event, caused more than **$11 million** in damage.
- The second most-damaging earthquakes were the October 1935 Helena earthquakes, which caused more than **$4 million** in damage.

(Sources: FEMA 2004e; USGS, 2003a; Stickney, 2000; NISEE, 1998)

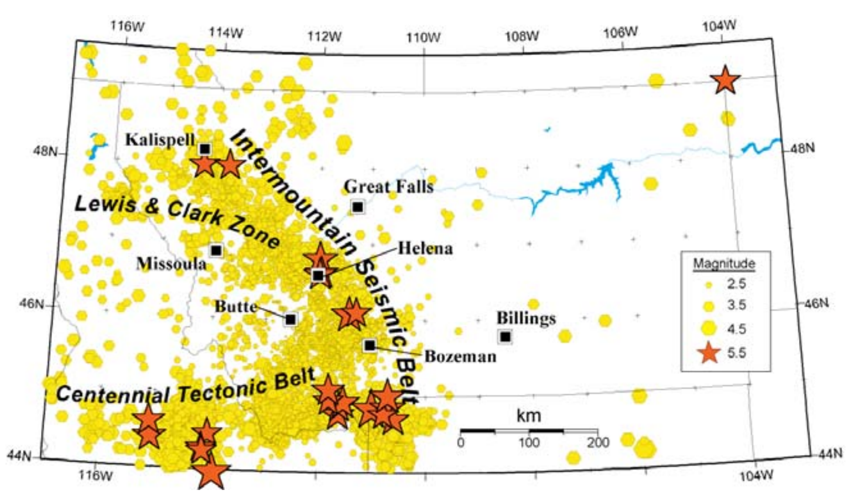


Figure 3.3.1-1 Intermountain Seismic Belt. A belt of seismicity known as the Intermountain Seismic Belt extends through western Montana, from the Flathead Lake region in the northwest corner of the state to the Yellowstone National Park region. Source: MBMG, 2004.

3.3.1.2 History of Earthquakes in Montana

Montana is one of the most seismically-active states in the United States. Since 1925, the state has experienced five shocks that reached intensity VIII or greater (Modified Mercalli Scale). During the same interval, hundreds of less severe tremors were felt within the state. Montana's earthquake activity is concentrated mostly in the mountainous western third of the state, which lies within the Intermountain Seismic Belt that also includes southeastern Montana, western Wyoming, and central Utah (**Figure 3.3.1-1**).

The first confirmed earthquake in Montana was reported in Helena in 1869. The strength of this quake caused houses to shake, overturning furniture and breaking dishes.

Table 3.3.1-1 shows the historic earthquakes of Montana and surrounding regions with magnitude of 5.5 or greater since 1900. Although one significant earthquake occurred in eastern Montana in 1909, the majority have occurred along the Intermountain Seismic Belt and Centennial Tectonic Belt in western Montana (note: dates are referenced to GMT).

Table 3.3.1-1 Historic Earthquakes of Montana and Surrounding Regions with Magnitudes of 5.5 or Greater since 1900. Source: Stickney, 2000.

Date	Magnitude	Approximate location
05/16/09	5.5	Northeast Montana
06/28/25	6.6	Clarkston Valley
02/16/29	5.6	Clarkston Valley
10/12/35	5.9	Helena
10/19/35	6.3	Helena
10/31/35	6.0	Helena
07/12/44	6.1	Central Idaho
02/14/45	6.0	Central Idaho
09/23/45	5.5	Flathead Valley
11/23/47	6.1	Virginia City
04/01/52	5.7	Swan Range
08/18/59	7.5	Hebgen Lake
08/18/59	6.5	Hebgen Lake
08/18/59	6.0	Hebgen Lake
08/18/59	5.6	Hebgen Lake
08/18/59	6.3	Hebgen Lake
08/19/59	6.0	Hebgen Lake
10/21/64	5.6	Hebgen Lake
06/30/75	5.9	Yellowstone Park
12/08/76	5.5	Yellowstone Park
10/28/83	7.3	Challis, ID
10/29/83	5.5	Challis, ID
10/29/83	5.5	Challis, ID
08/22/84	5.6	Challis, ID

Table 3.3.1-2 shows deaths and major damages from two major Montana earthquake events.

Table 3.3.1-2 Deaths and Damages from the Two Most Damaging Montana Earthquakes. Source: USGS, 2004a.

Date	Locality	Deaths	Damages	Damages in 2004 $
October 19, 1935	Helena, Montana	2	$4 million	$55 million
October 31, 1935	Helena, Montana	2		
August 18, 1959	Hebgen Lake, Montana	28	$11 million	$71 million

3.3.1.2.1 Largest Earthquake in Montana: Hebgen Lake, August 18, 1959 Magnitude 7.5, Intensity X

The Hebgen Lake Earthquake of 1959 was the largest earthquake in Montana and the 14th largest earthquake in the contiguous United States in historic times (Stover and Coffman, 1993). This earthquake caused 28 fatalities and about **$11 million** in damage to highways and timber. It was characterized by extensive fault scarps, subsidence and uplift, a massive landslide, and a seiche (large wave) in Hebgen Lake. A maximum intensity X or greater (Modified Mercalli Scale) was assigned to the epicentral area.

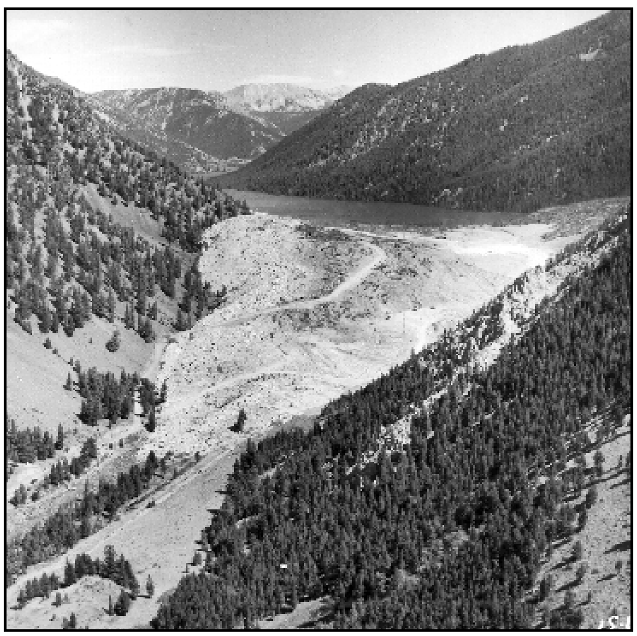


Photo 3.3.1-1 Aerial view of Madison Canyon slide with Earthquake Lake in the background. The Hebgen fault crosses the dark forested spur near the head of lake. Madison County, Montana. August 1959. Source: USGS, 2004a.

The most spectacular and disastrous effect of the earthquake was the huge landslide of rock, soil and trees that cascaded from the steep south wall of the Madison River Canyon. This slide formed a barrier that blocked the gorge and stopped the flow of the Madison River and, within a few weeks, created a lake almost 53 meters (174 feet) deep. The volume of material that blocked the Madison River below Hebgen Dam was estimated at 28 to 33 million cubic meters (988.8 to 1165.4 cubic feet). Most of the 28 deaths were caused by rockslides that covered the Rock Creek public campground on the Madison River, about 9.5 kilometers (5.9 miles) below Hebgen Dam.

Photo 3.1-2 Hebgen Earthquake (1959), Red Canyon fault scarp where it cut through the Blarneystone Ranch. The house sits on the down-thrown block. The fault scarp here is 10 to 12 feet high. The roof of a small collapsed shed is visible on the up-thrown block. Gallatin County, Montana. Source: USGS, 2004a.

New fault scarps as high as 6 meters (19.7 feet) formed near Hebgen Lake during this earthquake. The major fault scarps formed along pre-existing normal faults northeast of Hebgen Lake. The earth-fill dam sustained significant cracks in its concrete core and spillway, but it continued to be an effective structure.

Many summer houses in the Hebgen Lake area were damaged; houses and cabins shifted off their foundations, chimneys fell, and pipelines broke. Most small-unit masonry structures and wooden buildings along the major fault scarps survived with little damage when subjected only to vibratory forces. Roadways were cracked and shifted extensively, and much timber was destroyed. Highway damage near Hebgen Lake was due to landslides slumping vertically and flowing laterally beneath pavements and bridges, which caused severe cracks and destruction. Three of the five reinforced bridges in the epicentral area also sustained significant damage.

High intensity earth movements were observed in the northwest section of Yellowstone National Park. Here, new geysers erupted, and massive slumping caused large cracks in the ground from which steam emitted. Many hot springs became muddy.

3.3.1.2.2 Helena Earthquakes – Up to Magnitude 6.3

Starting with a small tremor on October 3, the City of Helena, Montana suffered through a devastating series of several hundred earthquake shocks in the month of October, 1935, including three damaging earthquakes on October 12th, 18th, and the 31st. Although no surface ruptures occurred during this earthquake sequence, shaking from the earthquakes damaged more than half of Helena's buildings. The epicenters of the 1935 series of earthquakes is not precisely known, but were probably located about 6 km (3.7 miles) north of the city, possibly along the Prickly Pear fault zone (Qamar & Stickney, 1983). The following description of the earthquake is from the National Information Service for Earthquake Engineering (NISEE, 1998).

Previous to the cluster Helena earthquake tremors there had been little recorded seismic activity in the area of Helena. The earthquakes disproved a then-popular misconception that all seismic activity within the United States occurred solely in California and Alaska. Before October 1935, the spurious sense of immunity from natural disaster contributed to an atmosphere of uncontrolled construction in Helena. Earthquake hazard and earthquake-resistant design methods were disregarded. Older, antiquated construction in Helena behaved predictably during the tremors.

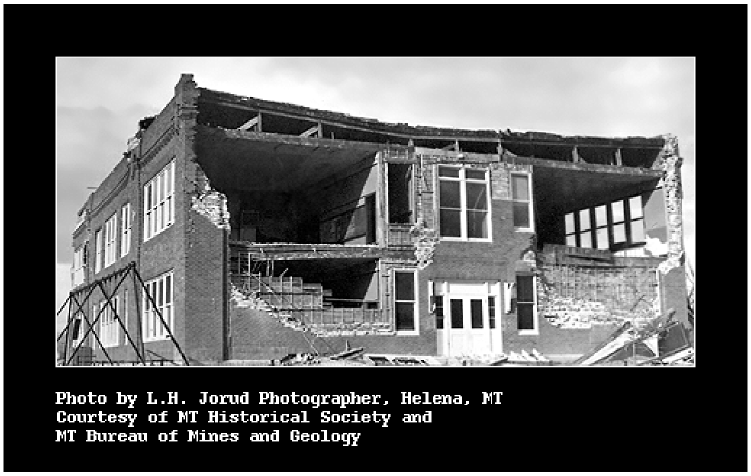


Photo 3.1-3 Bryant Elementary School in Helena, Montana, suffered increasing damage in the series of 1935 earthquakes which began October 12th. Until reconstruction was completed, its 276 students attended school in the basement of Central school. Source: Utah NEHRP, 2004.

Damage in Helena included collapsed chimneys, fallen parapets, gables, and end walls, shattered walls parallel to interior framing, with partial or total collapse of structures as the ultimate end. Most buildings with un-reinforced masonry-bearing walls were severely damaged within the month-long barrage of seismic activity. Likewise, industrial smoke stacks built almost entirely of brick fell down.

The inadequacies of existing structural design requirements became painfully obvious after a large earthquake. The October 18th earthquake brought serious damage to City Hall, as well as the area to the east of the mercantile district along Main Street. There, many chimneys fell down, brick dwellings were seriously damaged or partly collapsed, brick veneer was thrown off, and many commercial, school, and public buildings were greatly affected, some destroyed. The worst wreckage occurred in structures on the softer alluvial soil toward the valley, notably the new High School and the Bryant School.

The last large shock of October 31st caused the collapse of parts of buildings which previously had been seriously affected, but which remained standing, including the new High School and the Kessler Brewery. It also caused new damage in many structures not previously seriously affected. The failure of the high school is directly attributable to deficiencies in design. The skeleton frame was designed for vertical (not horizontal) loads and reinforced for such loads only. Walls could offer no stability to the frame. As a result, the walls broke up and shattered, and the frame was cracked or ruptured in many places.

3.3.1.3 Declared Disasters from Earthquakes

No declared disasters from the affects of earthquake damage have been made since 1974.

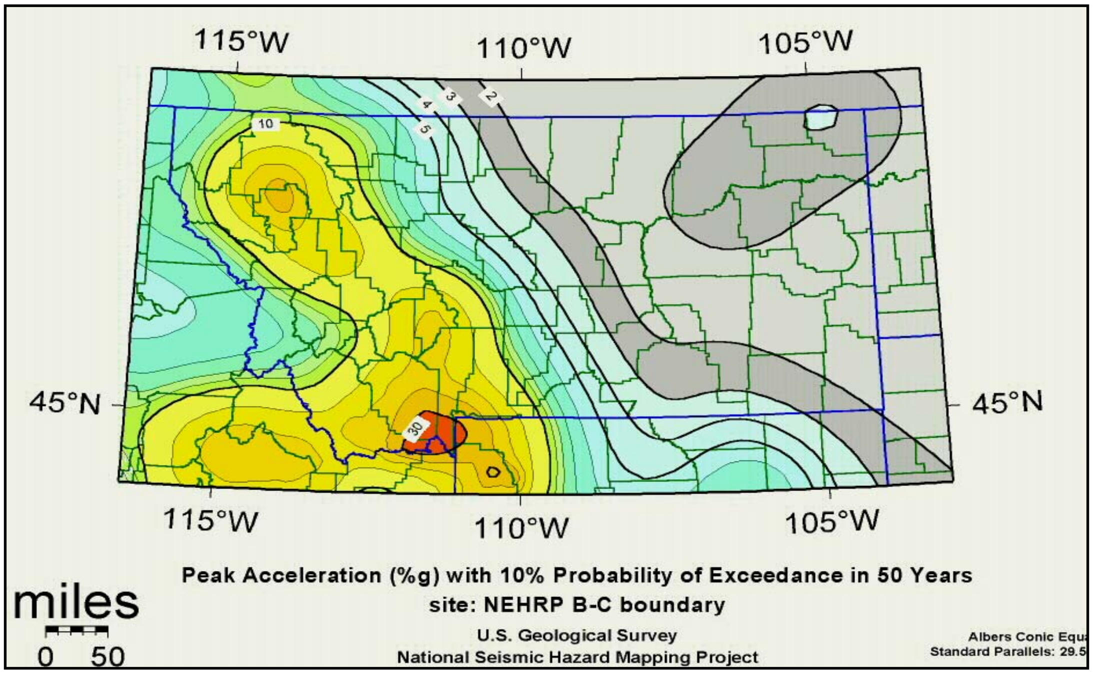
3.3.1.4 Vulnerability to Earthquakes

Earthquakes will undoubtedly continue to occur in Montana, however the precise time, location, and magnitude of future events cannot be predicted. As discussed above, earthquake hazard areas in Montana are concentrated in the western portion of the state, which is part of the Intermountain Seismic Belt (**Figure 3.3.1-1**). Numerous factors contribute to determining areas of vulnerability: historical earthquake occurrence, proximity to faults, soil characteristics, building construction, and population density, to mention a few.

3.3.1.4.1 Earthquake Hazard Areas

The US Geological Survey (USGS) has generated earthquake hazard areas (indicated by peak acceleration values) for the continental United States. The peak acceleration values applicable to Montana are shown in **Figure 3.3.1-2.** The contour values show the earthquake ground motions with a common probability of being exceeded in 50 years. The ground motions considered at a given location are those from all future possible earthquake magnitudes at all possible distances from that location. On a given map, for a given probability of exceedance, PE, locations shaken more frequently, will have larger ground motions.

Figure 3.3.1-2 Peak Acceleration Values in Montana. Source: USGS, 2004a.



As **Figure 3.3.1-2** shows, the southwest portion of the state is the most susceptible to future earthquakes. Considering both population concentration and historic seismicity, Helena and Bozeman are the most vulnerable locations, followed by Missoula, Butte and Kalispell. These areas also are experiencing some of the greatest population growth rates in the state. Without mitigation of earthquake effects, the potential for losses will increase as population growth and building and infrastructure development expands.

Seasonal tourism increases exposure to seismic hazards in all areas, but the greatest exposure is in the Yellowstone National Park-Hebgen Lake region, where several million people visit annually. The fact that the majority of the 28 fatalities associated with the 1959 Hebgen Lake earthquake were out-of-state visitors confirms this point. In contrast, Billings and Great Falls, respectively the first and third largest cities in the state, have relatively low earthquake hazard ratings.

3.3.1.4.2 Earthquake Loss Estimation Models

Earthquake losses were estimated by using the HAZUS (beta v 28.b) Earthquake model developed by the Federal Emergency Management Agency (FEMA). Counties with a high earthquake recurrence rates were compared by evaluating the annualized loss estimate in the HAZUS model. The annualized loss estimate addresses two key components of seismic risk: the probability of ground motion within a given study area and the consequences of the ground motion (FEMA, 2001). The result of a FEMA (2001) HAZUS analysis indicated that estimated annualized losses for the State of Montana are $15.6M, based on 1999 values.

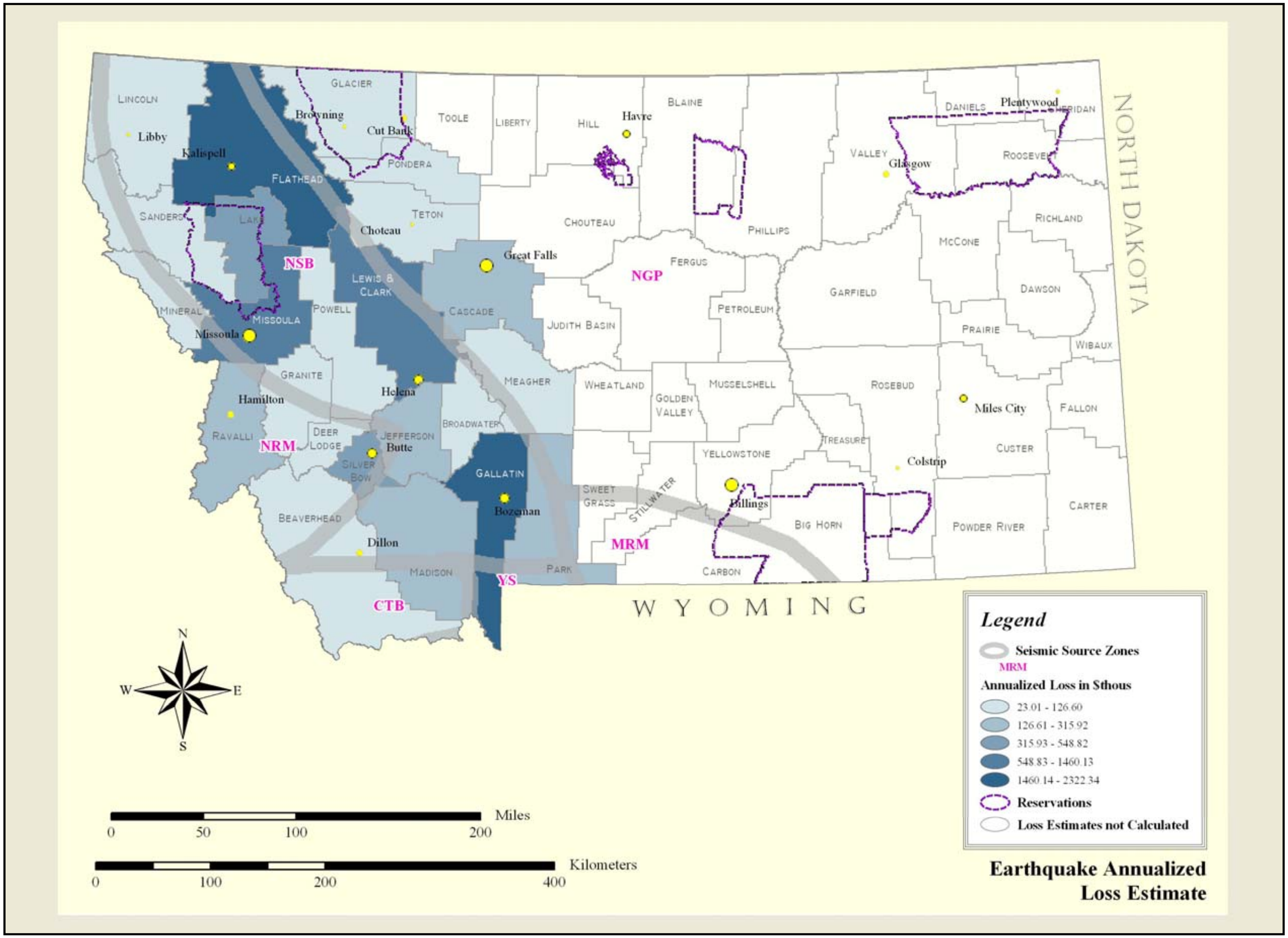
The HAZUS annualized loss estimate conducted for this Hazard Assessment uses default general building stock data in the model and estimates average losses per year by county. Counties with little history of earthquake activity were not included in the analysis. Ground motion was based on US Geologic Survey probabilistic motion default parameters in the model (see **Figure 3.3.1-2**). The analysis used the ground motion demand computed at the centroid of each census tract. The results show county-wide estimated losses on an annual basis for general building stock. The analysis was not completed on other critical facilities or infrastructure due to a lack of digital data for these locations.

Table 3.3.1-3 and **Figure 3.3.1-3** show the results of the HAZUS analysis for the 10 counties with the highest potential for earthquake damage. The analysis shows that Gallatin County would have the highest losses, followed by Flathead, Missoula, and Lewis and Clark Counties. This result is somewhat surprising, as Missoula County is considered to have a relatively low seismic activity (Qamar and Stickney, 1983), and no earthquakes above 5.0 on the Richter Scale have ever been documented in Missoula County. Its proximity to the Intermountain Seismic Belt and concentrated population base may increase its vulnerability over the more frequent, less populated areas.

Table 3.3.1-3 Ten counties with Highest Losses using the HAZUS Earthquake Annualized Loss Function.

County	Cost Structural Damage	Cost Non-Structural Damage	Cost Contents Damage	Inventory Loss	Wage/Income Related Loss	Loss Ratio	Total Annualized Loss
Gallatin	$276,920	$1,407,160	$453,090	$6,370	$178,800	.0237	$2,322,340
Flathead	$217,200	$1,098,980	$419,230	$6,340	$116,690	.0200	$1,858,440
Missoula	$202,250	$866,350	$262,630	$3,130	$125,770	.0118	$1,460,130
Lewis and Clark	$163,300	$730,480	$231,330	$2,420	$84,390	.0171	$1,211,910
Silver Bow	$76,720	$322,120	$96,330	$1,040	$52,610	.0134	$548,820
Lake	$57,730	$294,050	$115,950	$1,380	$28,090	.0167	$497,200
Ravalli	$47,690	$183,210	$57,420	$1,030	$26,580	.0083	$315,920
Cascade	$46,160	$164,590	$48,070	$510	$38,610	.0029	$297,930
Jefferson	$31,560	$144,540	$46,030	$210	$9,960	.0085	$232,300
Madison	$27,480	$141,540	$42,870	$650	$12,930	.0231	$225,460

Figure 3.3.1-3 Earthquake Annualized Loss Estimate



3.3.1.4.3 Earthquake Recurrence Intervals

Qamar and Stickney (1983) developed earthquake recurrence intervals for high-incidence seismic zones in the state based on historic earthquake information. Wong and others (in preparation) compiled a more complete historic earthquake catalog and used it to develop improved recurrence relations for five regional seismic source zones in Montana. The five regional source zones are: Northern Intermountain Seismic Belt, Centennial Tectonic Belt, Northern Rocky Mountains, Middle Rocky Mountains, and Northern Great Plains (**Figure 3.3.1-3**). These results suggest that a magnitude 6 or larger earthquake may strike the Northern Intermountain Seismic Belt once in a 23-year period. This seismic source zone includes the cities of Kalispell, Missoula, Helena, Bozeman, and Livingston, as well as the rapidly growing rural population and infrastructure surrounding those cities.

Table 3.3.1-4 Earthquake Recurrence Rates by Seismic Source Zone. Source: Wong and others (in preparation).

Seismic Source Zone	M*5	M*6	M*7	# Quakes M >=6
Northern Intermountain Seismic Belt	3.84	22.6	133.	1
Centennial Tectonic Belt	8.69	75.7	659.	1
Northern Rocky Mountains	36.6	420.	4821.	0
Middle Rocky Mountains	237.	1,754.	13,000.	0
Northern Great Plains	26.8	184.	1281.	2

* Predicted return time (in years) of earthquakes with magnitude M or greater.
Note: These values reflect recurrence times in the entire source zone defined by Wong and others.

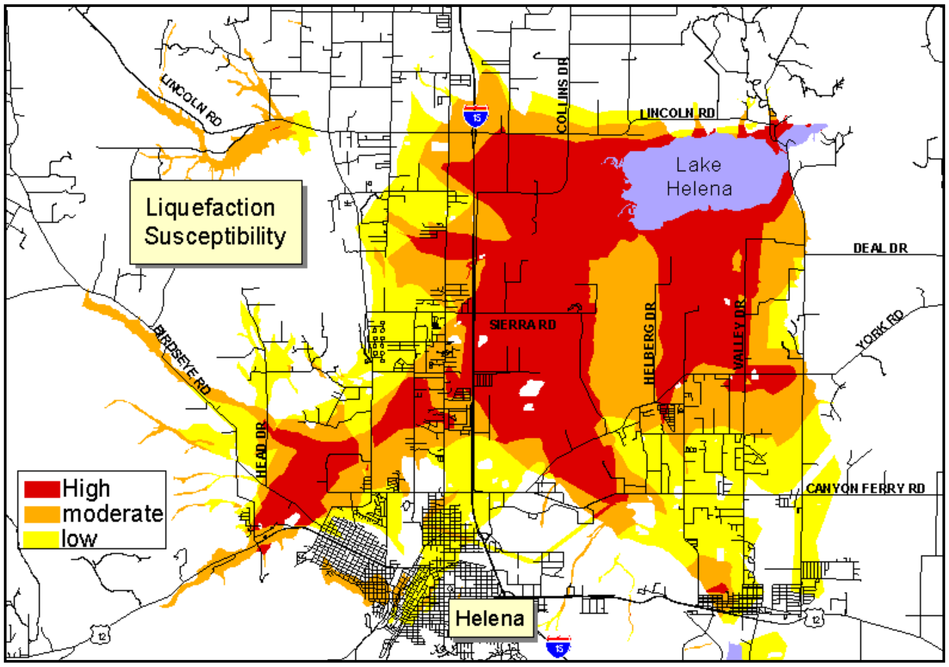
3.3.1.4.4 Review of Potential Losses in Local PDM Plans

Of the 6 counties that have completed Pre-Disaster Mitigation Plans only 2 identified earthquakes as a significant hazard.

- Broadwater County identified earthquake hazards as one of the top three hazards in the County. Using the FEMA HAZUS-99 computer model and default data, the county estimated about **$50 million** in property damages and up to **100 injuries/deaths** from a magnitude 7.0 earthquake on the Toston fault.
- Butte-Silver Bow County identified earthquakes as the hazard with greatest probability to impact the County. Using HAZUS-99 and default data, an earthquake has the potential to cause **$300 million** in property damages and up to **300 injuries/deaths** from a magnitude 6.0 earthquake.
- Yellowstone County determined the hazard to be low.

Helena is the only major city in Montana that is known to lie near an active fault capable of causing large earthquakes (Qamar and Stickney, 1983). Lewis & Clark County (2004) completed a HAZUS computer simulation of a **6.3 earthquake** in Helena. The simulation revealed that property damage would be nearly **$1 billion** for an earthquake of this magnitude. Fatalities and injuries would depend upon the time of day that the earthquake would occur, but may cause up to **12 deaths**. The model results estimated government building damage would be minimal, but the default government building data built into the model is poor and likely underestimates the potential damage. The Capitol Complex is located in areas that have a very low potential of liquefaction susceptibility. A liquefaction susceptibility map for the Helena Valley is shown in **Figure 3.3.1-4.**

Figure 3.3.1-4 **Liquefaction susceptibility map for the Helena Valley.**
Source: Lewis & Clark County, 2004



3.3.1.4.5 Vulnerability of State Property

An analysis of direct exposure of government buildings and infrastructure has not been completed. The default data of government buildings in the HAZUS earthquake prediction model is inadequate to assess structural, non-structural, and content losses. To effectively determine earthquake vulnerability for State property, data identifying locations of State buildings is necessary to determine the exposure and vulnerability. The current PCIIS building database is not geo-referenced and cannot be effectively related to spatial coordinates except in general locations (by city or zip code centroid).

Counties that are highly vulnerable to earthquake loss are those where the annualized earthquake loss ratio is greater than 0.01. **Table 3.3.1-5** below shows the counties that meet that criteria and the total value of state buildings and contents that are exposed to earthquake loss.

Table 3.3.1-5 State-Owned Buildings in Counties Highly Vulnerable to Earthquakes

County	Annualized Loss Ratio	Building Value	Contents Value	Total Value	FTEs
Gallatin	.0237	$413,209,424	$281,332,610	$694,542,034	2,875
Madison	.0231	$11,224,637	$402,171	$11,626,808	9
Broadwater	.0214	$12,731,540	$8,896,063	$21,627,603	4
Flathead	.0200	$28,929,471	$7,916,880	$36,846,351	438
Jefferson	.0185	$23,409,061	$7,537,652	$30,946,713	262
Lewis and Clark	.0171	$254,998,224	$125,124,161	$380,122,385	6,283
Lake	.0167	$3,424,220	$1,093,218	$4,517,438	75
Silver Bow	.0134	$72,856,024	$33,575,041	$106,431,065	398
Powell	.0130	$62,140,542	$12,434,271	$74,574,813	456
Beaverhead	.0124	$41,771,660	$14,183,864	$55,955,524	625
Sanders	.0118	$913,908	$570,585	$1,484,493	33
Missoula	.0118	$391,640,945	$151,210,662	$542,851,607	3,375
Park	.0106	$2,063,368	$847,125	$2,910,493	48
Meagher	.0100	$388,101	$74,802	$462,903	4
TOTALS		**$1,319,701,125**	**$645,199,105**	**$1,964,900,230**	**14,885**

From PCIIS database (2004), Montana Department of Administration, Risk Management & Tort Defense Division.

3.3.1.5 Earthquake Data Limitations

The default data of government buildings in the HAZUS earthquake prediction model is very inadequate. To effectively determine earthquake vulnerability of State property, data identifying locations of State buildings is necessary. The current PCIIS building database is not geo-referenced and cannot be effectively related to spatial coordinates except in general locations (by city or zip code centroid).

Fault mapping and specific local-level hazard mapping (such as liquefaction) is incomplete across the State. Many faults within the State are believed to be unmapped or not studied. Improvements to HAZUS data and continuing research in the areas of geology and earthquakes could significantly improve the vulnerability assessment.

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